

An entertaining task for artificial intelligence



Objective of the Work

The objective of this project is to demonstrate practical skills in applying artificial intelligence to solve problems related to the optimal distribution of welding points among robots on **an improvised automated line**, with the aim of minimizing the line cycle time and reducing equipment wear.

Task Description

This work considers an automated welding line as an example and addresses the following task:

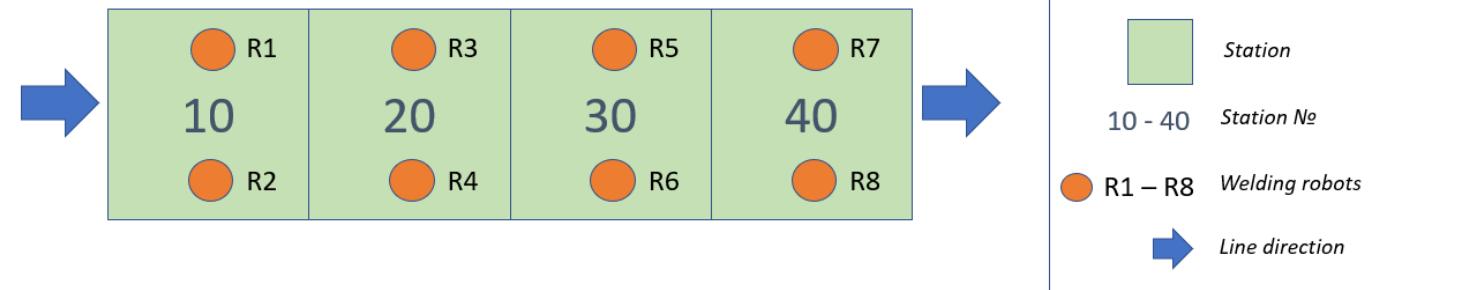
- **Optimization of line cycle time:** distribution of welding points among robots in order to minimize the operating time of each station, taking into account parallel robot operation and sequential part movement.

Description of the Automated Line

The automated line (hereinafter referred to as AL) is a set of technical systems that automatically perform spot welding operations in a defined technological sequence.

AL configuration:

- 4 stations
- 8 industrial robots
- 8 spot welding guns
- automated transport system for moving the part between stations



The AL consists of four stations (operations): 10, 20, 30, and 40. Each station is equipped with two robots located on opposite sides of the station: left and right. The side is defined by the direction of the technological process.

The left side of the AL includes robots R1, R3, R5, and R7. The right side includes robots R2, R4, R6, and R8.

Welding guns are installed on the robots. For each gun, its weight, wear level, and welding time per single point are specified.

Station Dimensions

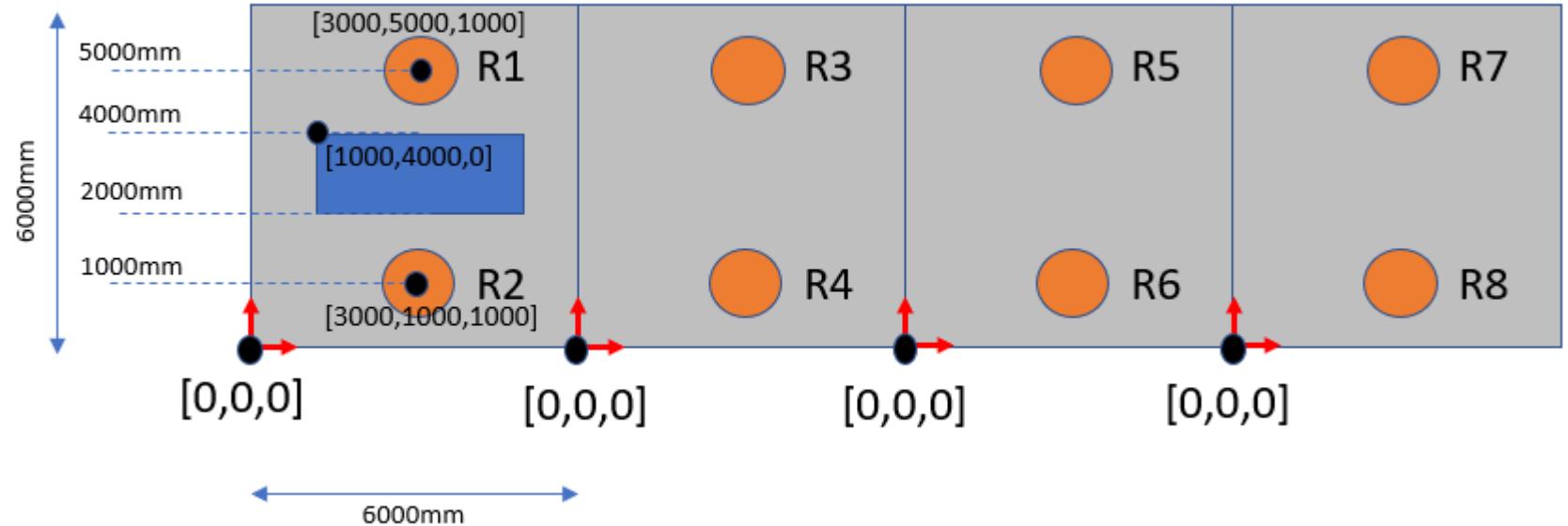
Length: 6 meters

Width: 6 meters

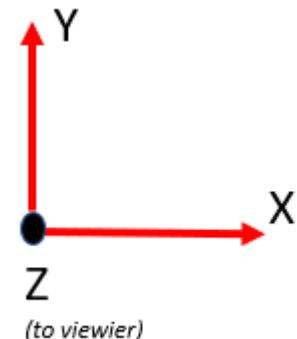
Total AL length: 24 meters

Station Coordinate System

Each station of the automated line has its own coordinate system. The origin of the coordinate system is located at the lower left corner of the station.



The X-axis is directed along the automated line, the Y-axis is directed toward the left side of the line, and the Z-axis is directed upward.



Robot Coordinates

Robots R1, R3, R5, and R7 have identical positions at their respective stations. The tool center point (TCP) of these robots has the following coordinates: [X: 3000, Y: 5000, Z: 1000] mm.

Z = 1000 mm indicates that the TCP of the welding gun is located at a height of 1 meter above the floor level.

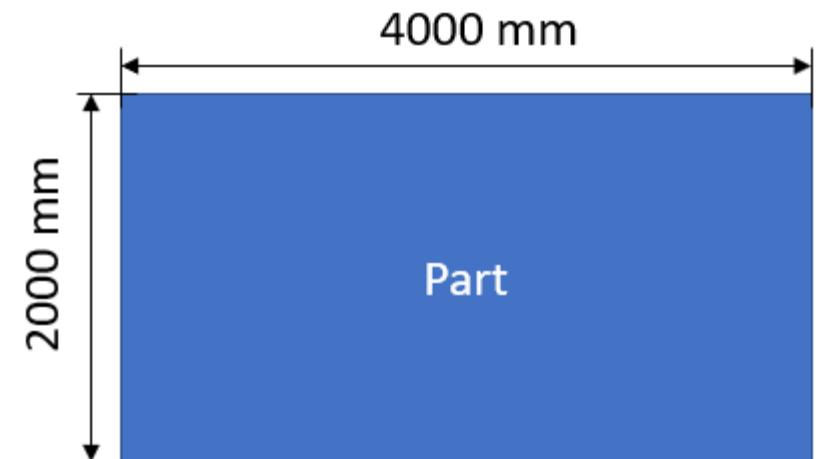
According to the task conditions, the TCP coordinates [X: 3000, Y: 5000, Z: 1000] represent the home (initial) position of the robots.

Work Object Coordinates

A work object is located within the station coordinate system. The position of the part corresponds to the position of the work object.

Work object and part dimensions:

- Length: 4 meters
- Width: 2 meters



Along the direction of the technological process, the part is conditionally divided into left and right sides. The part is also divided into segments, each containing a defined number of welding points.

Not all segments are accessible to all robots due to structural limitations of the welding guns. This constraint is intentionally introduced to increase task complexity.

Diagram of part segments showing the number of welding points and the robots with access to them

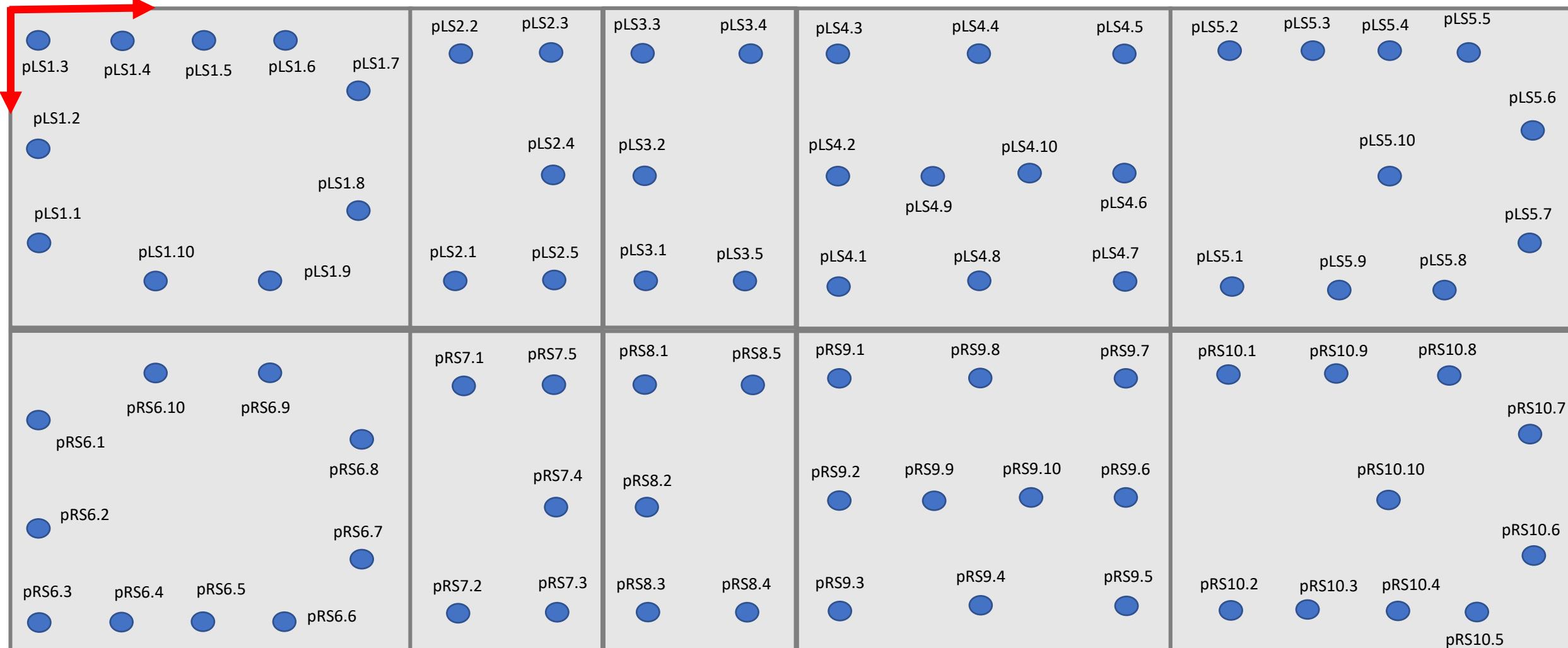
	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	
Left side	<i>10 points</i> R1	<i>5 points</i> R1, R3	<i>5 points</i> R1, R3	<i>10 points</i> R5, R7	<i>10 points</i> R5, R7	R1 – Gun1 - GType_1 R3 – Gun2 - GType_2 R5 – Gun3 - GType_3 R7 – Gun4 - GType_3
Right side	<i>10 points</i> R2	<i>5 points</i> R2, R4	<i>5 points</i> R2, R4	<i>10 точек</i> R6, R8	<i>10 points</i> R6, R8	R2 – Gun5 - GType_1 R4 – Gun6 - GType_2 R6 – Gun7 - GType_3 R8 – Gun8 - GType_3
	Segment 6	Segment 7	Segment 8	Segment 9	Segment 10	

Welding points are distributed among segments. Their number on the left and right sides is identical, with mirror-symmetric placement.

Diagram of the arrangement of welding points on the part

X 4000 mm

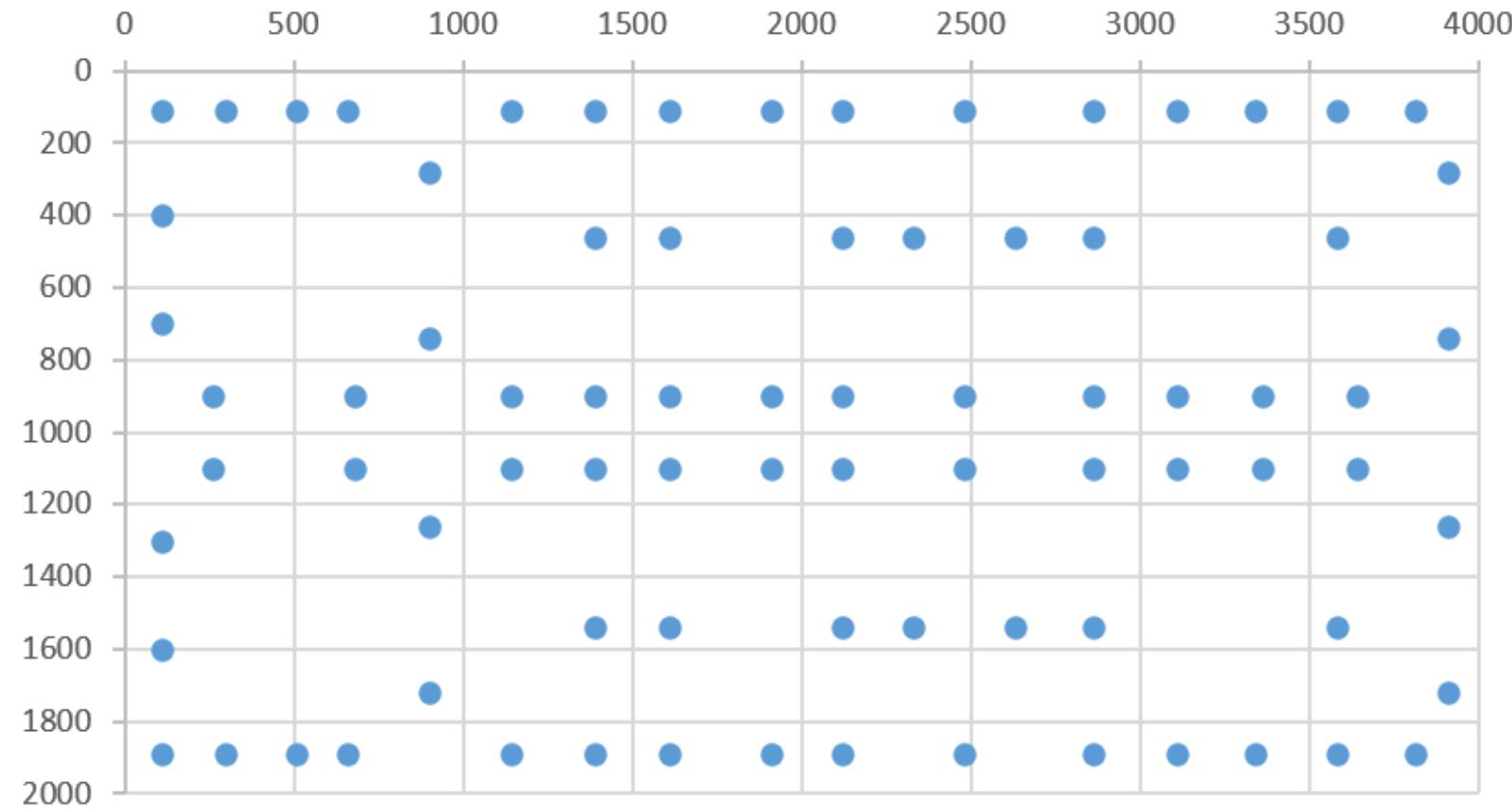
0,0



Y 2000 mm

For additional complexity, the Y-axis of the work object coordinate system is oriented opposite to the Y-axis of the station coordinate system. The origin of the work object coordinate system is located in the upper left corner.

Each welding point has X, Y, Z coordinates defined in the work object coordinate system.



Initial data

Table. Automated Line Composition:

Station No.	Station Side	Robot	Station Length (X), mm	Station Width (Y), mm
10	Left Side	R1	6000	6000
	Right Side	R2	6000	6000
20	Left Side	R3	6000	6000
	Right Side	R4	6000	6000
30	Left Side	R5	6000	6000
	Right Side	R6	6000	6000
40	Left Side	R7	6000	6000
	Right Side	R8	6000	6000

Note: Each station has its own independent coordinate system. The beginning of the countdown is the lower left corner. Horizontally to the right is the X-axis, vertically up is the Y-axis.

Table. Robot List:

Robot	Part Side	Welding Gun	Robot object	Home pos.			Robot speed, mm/s	Electrode stripping interval, cycles	Electrode stripping time, sec.
				X	Y	Z			
R1	Left Side	Gun1	Tobj	3000	5000	1000	3000	50	10
R3	Left Side	Gun2	Tobj	3000	5000	1000	3000	50	10
R5	Left Side	Gun3	Tobj	3000	5000	1000	3000	50	10
R7	Left Side	Gun4	Tobj	3000	5000	1000	3000	50	10
R2	Right Side	Gun5	Tobj	3000	1000	1000	3000	50	10
R4	Right Side	Gun6	Tobj	3000	1000	1000	3000	50	10
R6	Right Side	Gun7	Tobj	3000	1000	1000	3000	50	10
R8	Right Side	Gun8	Tobj	3000	1000	1000	3000	50	10

Note: the coordinates of the object and the robot's tool (TCP) are plotted in the coordinate system of the station

Table. Welding guns

Welding Gun	Type	Welding time of one point, sec	Weight, kg	Degree of wear, %
Gun1	GType_1	2	150	0
Gun2	GType_2	2	170	10
Gun3	GType_3	2	120	40
Gun4	GType_3	2	145	25
Gun5	GType_1	2	150	10
Gun6	GType_2	2	170	5
Gun7	GType_3	2	120	15
Gun8	GType_3	2	145	0

Table. Robot object

Obj	X	Y	Z
Tobj	1000	4000	0

Note: The origin of the coordinate system is the upper-left corner. Horizontally is the X-axis, vertically is the Y-axis.

Table. Transport

Moving from	Moving to	Moving time, sec
10	20	8
20	30	8
30	40	8

Table. Assigning welding guns to welding points

Welding point #	Part segment	Type welding gun	Robot object	Coordinates		
				X	Y	Z
pLS1.1	1	GType_1	Tobj	110	700	0
pLS1.2	1	GType_1	Tobj	110	400	0
pLS1.3	1	GType_1	Tobj	110	110	0
pLS1.4	1	GType_1	Tobj	300	110	0
pLS1.5	1	GType_1	Tobj	510	110	0
pLS1.6	1	GType_1	Tobj	660	110	0
pLS1.7	1	GType_1	Tobj	900	280	0
pLS1.8	1	GType_1	Tobj	900	740	0
pLS1.9	1	GType_1	Tobj	680	900	0
pLS1.10	1	GType_1	Tobj	260	900	0
pLS2.1	2	GType_1, GType_2	Tobj	1140	900	0
pLS2.2	2	GType_1, GType_2	Tobj	1140	110	0
pLS2.3	2	GType_1, GType_2	Tobj	1390	110	0
pLS2.4	2	GType_1, GType_2	Tobj	1390	460	0
pLS2.5	2	GType_1, GType_2	Tobj	1390	900	0
pLS3.1	3	GType_1, GType_2	Tobj	1610	900	0
pLS3.2	3	GType_1, GType_2	Tobj	1610	460	0
pLS3.3	3	GType_1, GType_2	Tobj	1610	110	0
pLS3.4	3	GType_1, GType_2	Tobj	1910	110	0
pLS3.5	3	GType_1, GType_2	Tobj	1910	900	0
pLS4.1	4	GType_3	Tobj	2120	900	0
pLS4.2	4	GType_3	Tobj	2120	460	0
pLS4.3	4	GType_3	Tobj	2120	110	0
pLS4.4	4	GType_3	Tobj	2480	110	0
pLS4.5	4	GType_3	Tobj	2860	110	0
pLS4.6	4	GType_3	Tobj	2860	460	0
pLS4.7	4	GType_3	Tobj	2860	900	0
pLS4.8	4	GType_3	Tobj	2480	900	0
pLS4.9	4	GType_3	Tobj	2330	460	0
pLS4.10	4	GType_3	Tobj	2630	460	0
pLS5.1	5	GType_3	Tobj	3110	900	0
pLS5.2	5	GType_3	Tobj	3110	110	0
pLS5.3	5	GType_3	Tobj	3340	110	0
pLS5.4	5	GType_3	Tobj	3580	110	0
pLS5.5	5	GType_3	Tobj	3810	110	0
pLS5.6	5	GType_3	Tobj	3910	280	0
pLS5.7	5	GType_3	Tobj	3910	740	0
pLS5.8	5	GType_3	Tobj	3640	900	0
pLS5.9	5	GType_3	Tobj	3360	900	0
pLS5.10	5	GType_3	Tobj	3580	460	0

Table. Assigning welding guns to welding points

Welding point #	Part segment	Type welding gun	Robot object	Coordinates		
				X	Y	Z
pRS6.1	6	GType_1	Tobj	110	1300	0
pRS6.2	6	GType_1	Tobj	110	1600	0
pRS6.3	6	GType_1	Tobj	110	1890	0
pRS6.4	6	GType_1	Tobj	300	1890	0
pRS6.5	6	GType_1	Tobj	510	1890	0
pRS6.6	6	GType_1	Tobj	660	1890	0
pRS6.7	6	GType_1	Tobj	900	1720	0
pRS6.8	6	GType_1	Tobj	900	1260	0
pRS6.9	6	GType_1	Tobj	680	1100	0
pRS6.10	6	GType_1	Tobj	260	1100	0
pRS7.1	7	GType_1, GType_2	Tobj	1140	1100	0
pRS7.2	7	GType_1, GType_2	Tobj	1140	1890	0
pRS7.3	7	GType_1, GType_2	Tobj	1390	1890	0
pRS7.4	7	GType_1, GType_2	Tobj	1390	1540	0
pRS7.5	7	GType_1, GType_2	Tobj	1390	1100	0
pRS8.1	8	GType_1, GType_2	Tobj	1610	1100	0
pRS8.2	8	GType_1, GType_2	Tobj	1610	1540	0
pRS8.3	8	GType_1, GType_2	Tobj	1610	1890	0
pRS8.4	8	GType_1, GType_2	Tobj	1910	1890	0
pRS8.5	8	GType_1, GType_2	Tobj	1910	1100	0
pRS9.1	9	GType_3	Tobj	2120	1100	0
pRS9.2	9	GType_3	Tobj	2120	1540	0
pRS9.3	9	GType_3	Tobj	2120	1890	0
pRS9.4	9	GType_3	Tobj	2480	1890	0
pRS9.5	9	GType_3	Tobj	2860	1890	0
pRS9.6	9	GType_3	Tobj	2860	1540	0
pRS9.7	9	GType_3	Tobj	2860	1100	0
pRS9.8	9	GType_3	Tobj	2480	1100	0
pRS9.9	9	GType_3	Tobj	2330	1540	0
pRS9.10	9	GType_3	Tobj	2630	1540	0
pRS10.1	10	GType_3	Tobj	3110	1100	0
pRS10.2	10	GType_3	Tobj	3110	1890	0
pRS10.3	10	GType_3	Tobj	3340	1890	0
pRS10.4	10	GType_3	Tobj	3580	1890	0
pRS10.5	10	GType_3	Tobj	3810	1890	0
pRS10.6	10	GType_3	Tobj	3910	1720	0
pRS10.7	10	GType_3	Tobj	3910	1260	0
pRS10.8	10	GType_3	Tobj	3640	1100	0
pRS10.9	10	GType_3	Tobj	3360	1100	0
pRS10.10	10	GType_3	Tobj	3580	1540	0

CORRECT OPTIMIZATION IS

MIN time



Station	Side	Robot	Part Segment	Welding Spots (Left Side Example)	Number of Spots	Robot Cycle Time (sec, est.)
10	Left	R1	1	pLS1.1, pLS1.2, pLS1.3, pLS1.4, pLS1.5, pLS1.6, pLS1.7, pLS1.8, pLS1.9, pLS1.10	10	20.8
10	Right	R2	6	pRS6.1, pRS6.2, pRS6.3, pRS6.4, pRS6.5, pRS6.6, pRS6.7, pRS6.8, pRS6.9, pRS6.10	10	20.8
20	Left	R3	2, 3	pLS2.1-pLS2.5, pLS3.1-pLS3.5	10	20.8
20	Right	R4	7, 8	pRS7.1-pRS7.5, pRS8.1-pRS8.5	10	20.8
30	Left	R5	4	pLS4.1-pLS4.10	10	20.8
30	Right	R6	9	pRS9.1-pRS9.10	10	20.8
40	Left	R7	5	pLS5.1-pLS5.10	10	20.8
40	Right	R8	10	pRS10.1-pRS10.10	10	20.8

The main sign is that the answer is correct

Lets check with  deepseek

PROMPT

Collisions are not analyzed. This is a topic for future research.

You are a process engineer. An automatic line with robots is used at the plant for spot welding of a part. The automatic line has 4 stations.

Robots are located on the right and left sides of the automatic line, one for each station.

Initial data is presented in the attached files.

Each robot on the right side of a station works in parallel with the robot on the left side of the same station. Robots on the right side cannot weld the left side of the part and vice versa. The station cycle time is determined by the maximum operation execution time of any robot at that station. One welding spot cannot be welded more than once. All robots must be used for welding the part.

Each station has its own coordinate system.

The coordinates of the object and the robot tool (TCP) are built in the station's coordinate system. The coordinates of the welding spots are built in the object's coordinate system. The axes of the station and object coordinate systems are opposite in direction.

The origin of the station coordinate system is the bottom left corner. The X-axis extends horizontally to the right, the Y-axis vertically upwards.

The origin of the object coordinate system is the top left corner. The X-axis is horizontal, the Y-axis is vertical.

Transformation of object coordinates to station coordinates is performed using the formula:

- $X_{\text{station}} = X_{\text{Tobj}} + X_{\text{spot}}$
- $Y_{\text{station}} = Y_{\text{Tobj}} - Y_{\text{spot}}$

The part moves from station to station sequentially.

Process description:

- The transport with the part arrives at an empty station 10; the robots at station 10 are in their home position.
- Welding permission: Robots begin welding the part at station 10, starting from the home position. Upon completion of welding, the robots return to their home position.
- The transport with the part moves to the next station, 20.
- Then welding begins at station 20, similar to station 10.

The workflow at other stations is built in a similar way.

After unloading the part from station 40, the transport goes to fetch a new part for the loading operation.

Calculate the station cycle time using the formula (example for station 10):

$$T_{\text{station_10}} = \max(T_{\text{R1}}, T_{\text{R2}}) + T_{\text{transport}}$$

Instruction.

1. Distribute the welding spots among the robots to achieve the MINIMUM OPERATING TIME FOR EACH STATION. Provide a step-by-step calculation. Show the best option.

Format the result for the first solution in tables:

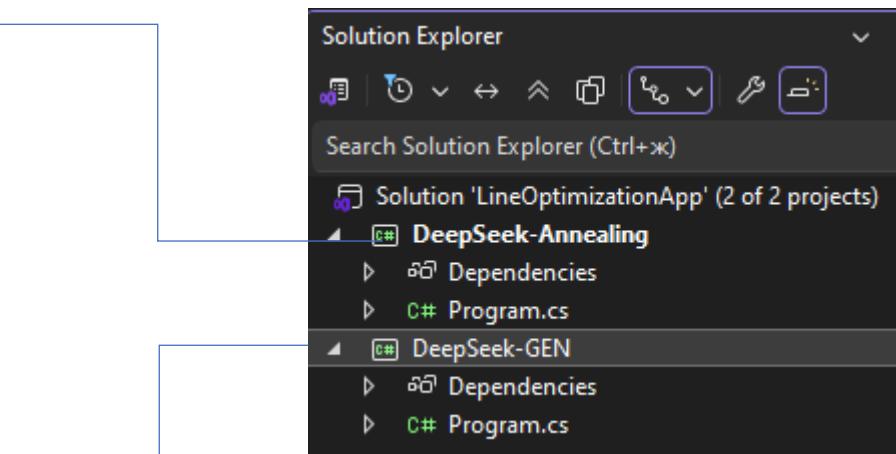
- Table with fields: Station, Side, Robot, Part Segment, Welding Spots, Number of Spots, Robot Cycle Time (sec).
- In the "Part Segment" field, list the segments processed by the robot, separated by commas.
- In the "Welding Spots" field, list the spots processed by the robot.
- Table with fields: Station, Number of Spots, Station Cycle Time (sec).
- Table with fields: Robot, Welding Gun Type, Welding Spots.

Before outputting the result, check:

- Each welding spot is welded only once,
- All robots are involved in the work,
- Robots on the right side do not weld the left side of the part and vice versa,
- The opposite direction of the axes of the station and object coordinate systems is taken into account,
- The compatibility of welding gun types is taken into account,
- The best solution for optimizing the distribution of welding spots among robots is found.

Creating a C# program using artificial intelligence

Optimization with simulated annealing algorithm



Optimization using a genetic algorithm

In the future, other optimization algorithms can be added for comparison.